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HMC Column structure design under Natural & Pre-stress Vibration Condition

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Abstract - *Horizontal Machining Center which employs a spindle that is parallel to the ground floor. With a horizontally oriented spindle, tools stick out of the side of the tool holder and cut across the side of a work piece. Main function of HMC is to perform heavy duty cuts under heavy payloads. In HMC column is the central part and it should be design in such a way that it can perform better in that condition. Machine is being classified according to capacity in which MHX-630 is being used in this case.MHX-630 is having moving column configuration and column design should be done for maintaining overall stiffness to weight ratio in machine structure for rigidity of the machine. Different type of column structure modeled in CREO as well as ANSYS is being utilized for validating the structure stability under given condition. Considering pre-stress condition in face milling and drilling operation column structure is being analyze.*

***Key Words*:** Pre-Stress, Structure, Stiffness, HMC, Column, Structural rigidity.

1. INTRODUCTION

In order to play its part in the production process a machine tool must satisfy following things

(1) Within permissible limits a specified accuracy of shape and dimensions of the work piece produced on the machine together with the required surface finish must be obtained consistently and, as far as possible, independently of the skill of the operator.

(2) In order to be competitive in operation, it must show high technical performance with economic efficiency. When considering the design of such a machine tool its elements can be divided into three groups, viz.

(a) The structure;
(b) The drives for the cutting, feed and setting movements;
(c) The operating and control devices. In this work full consideration will be given to the first of these, viz. the machine tool column structure which is the main part of machine tool where spindle is getting assembled.

1.1 Structure consideration

The structure of the machine has a decisive influence on the three main parameters that define the capabilities of a machine, which are: motion accuracy, the productivity of the machine and the quality of machining. In this respect, this study on structural components will add a new basic parameter, eco-efficiency, because the structure of the machine also has a decisive influence on the whole life cycle of the machine and especially on the materials and energy resources consumed.

Rams and columns have in most cases a square section to achieve a symmetrical and balanced behaviour concerning bending and torsion resistance. As the length of these components is defined by the strokes of the machine, there are two important aspects in designing rams and columns:

1) To define the appropriate thickness for their outer walls, and
2) To appropriately place internal ribs as a means of reaching an optimised stiffness-to-mass ratio.

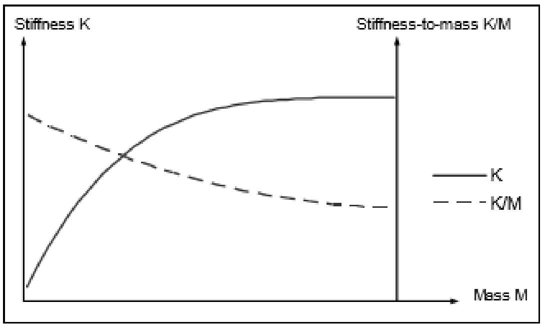

Fig-1 Influence of wall thickness (and mass) on ram stiffness

High natural frequencies can be obtained by combining high stiffness with low weight, especially if the weight is suitably distributed within the structure. Stiffness-to-weight ratio and the actual total weight, which affects the consumption and cost of material, can be affected to a large extent by the design layout. Thin-walled large box sections, as high stiffness to-weight ratios with resulting high natural frequency and safety against resonance.

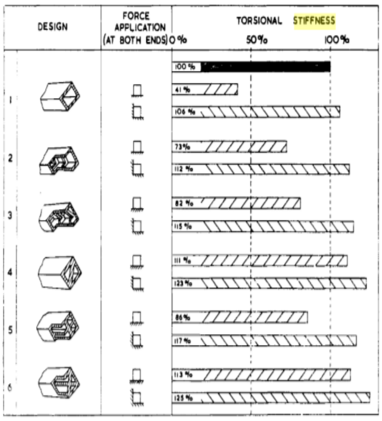

Fig-2 Effects of Stiffener

Hence we have selected box type structure for designing of column structure for attaining maximum stiffness to withstand the heavy payload.

2 Column Structure Design

Column structure design consideration and concept generation is made using PTC CREO 4.0. As per the research and past experience three structure of column is being made and natural frequency for each structure is being calculated for identifying the structural behavior of column. Consideration for concept design is:

- Increase the natural frequency
- Reduce the Weight
- Increase the stiffness of structure
- Increase the surface area for proper thermal distribution.

Material	Grey Cast Iron
Density	7200 Kg/m3
Young Modulus	110000 MPA
Poison Ratio	0.26

Table-1 Material Properties of column

2.2 Column Design Structure Concepts

Considering type of structure three concepts for column structure is created for identification of proper structure design with considering weight and stiffness of structure.

Concepts:-

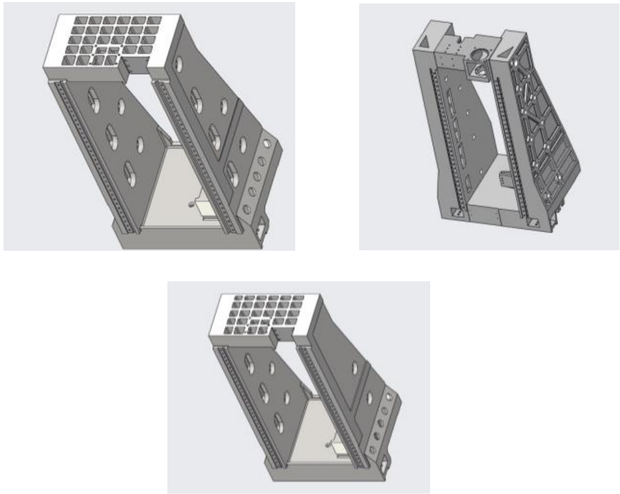

Fig-3 Column concepts

All three concepts are designed with considering structural stability, Stiffness and weight of column while designing considered box type rib structure which is having more stability and high natural frequency. Considering weight of the column concept 1 is having less weight so for optimization point of view.

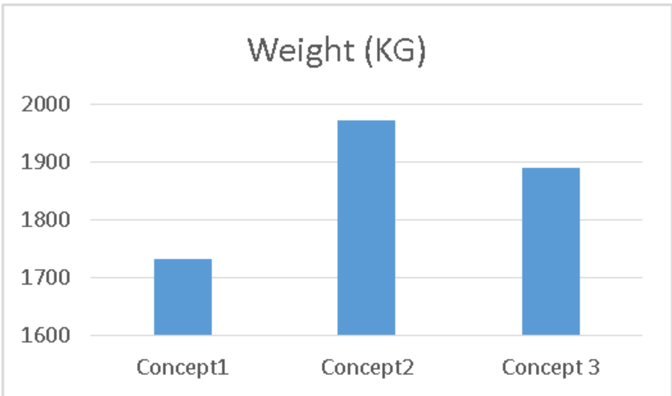

Chart -1: Wight of concept

2.3 Dynamic condition of HMC

As spindle is rotating with 6000 RPM which is the dynamic components which is mounted with this column structure hence considering this dynamic frequency column structure should withstand up to this dynamic frequency in steady state condition.

Name	Value
Maximum Rating Power(kW)	18.5 KW
RPM of BT-50 Spindle Motor	6000 RPM
Dynamic Frequency of spindle Motor(1 RPM=1/60 Hz)	100 Hz

Table -2: Frequency of spindle motor

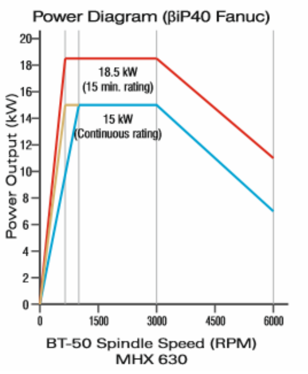

Fig-4 P-T Diagram

As per P-T diagram spindle motor is having maximum 6000 RPM and 18.5 KW Power. This diagram is taken from reference of industrial requirement. Spindle is dynamic component of machine which will directly mounted on the column. Hence following are the parameters that can be taken in account directly from machine specification.

Hence natural frequency of column nearby 100 Hz will absorb whole strain energy and make structure instable against force application.

3. Modal Analysis of Column structure concept

ANSYS 18.0 is being utilized for simulation and for finding natural frequency is for identifying natural behavior of structure. Simulation of all model will gives their deformation values at Natural frequency and from that we can select best structure design which gives more stability in terms of machining operation.

Boundary Condition: - Natural frequency can be identify by applying all boundary condition as fixed so it's applicable for all three concepts.

Loading condition: - For finding Natural frequency No Load is applied in modal. Modal analysis gives distribution of force over a system in both at initial level as well as at pre-stress level.

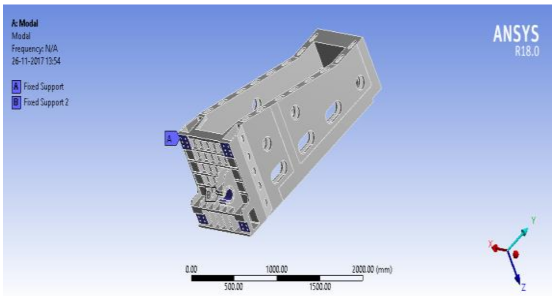

Fig -5: Boundary condition

Name	Number of Nodes	Number of Elements
Concept 1	143432	81824
Concept 2	206006	126128
Concept 3	139639	79990

Table -3: Discretization details

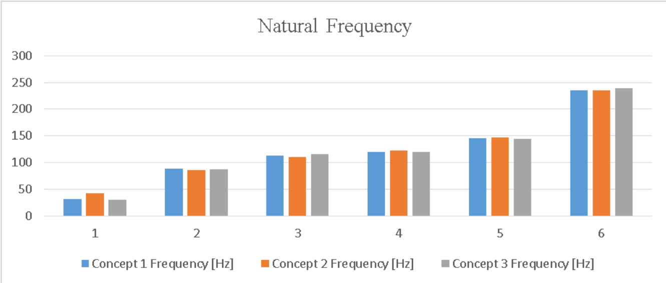

Chart -2: Comparison of Natural frequency for concepts

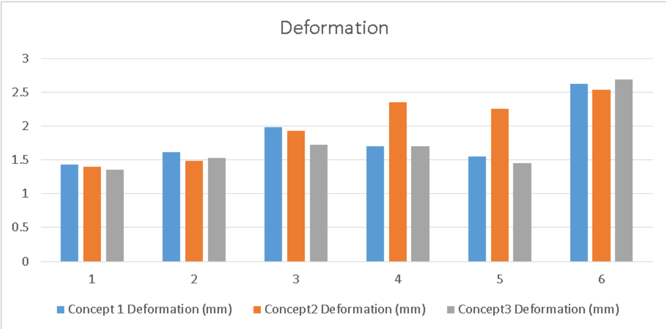

Chart -3: Comparison of deformation for concepts

Here from simulation result it's easily identify that concept3 & concept1 is having almost same natural frequency but Concept 1 is having less weight so concept 1 is best suitable for column structure because as the mass decreases stiffness of a component is getting increases.

4. CUTTING FORCE CALCULATION

Forces experienced by a tool during cutting is detrimental in design of mechanical structure of cutting machine, predicting power consumption, determining the tool life and increasing the productivity.

Most of the time cutting force acting on a tool is measured experimentally. But it is also important to predict quantity of cutting force and how different cutting parameters are affecting cutting force even before setting up the machining operation due to following reasons.

1) In order to design of mechanical structure of cutting machine which will withstand cutting force and thrust force effectively.

2) To determine power consumption during machining process. This will help in selecting suitable motor drive.
3) To predict tool life.
4) To increase productivity.
5)

Here only cutting force is being identified for only two operation:-

1. **Face Milling**: - Tangential cutting forces overcome the resistance to rotation and account for 70 % of the total force. Feed forces account for 20 % of the total force. Radial forces tend to push away the tool accounts 10 percent of the Cutting force.
2. **Drilling**:- Axial thrust & torque

4.1 Face Milling Calculation by Software

Cutter Diameter (mm)	Feed (mm)	Cutting Speed (m/min)	Depth of cut(MM)	Cutting Force Ft (N)	Torque (Nm)	Motor Power Pm (Kw)
100	0.3	146	8	6188.2	309410	15.1
100	0.3	146	5	3867.6	193380	10.44
150	**0.3**	**146**	**12**	**6864.4**	**514830**	**18.56**
150	0.2	120	12	4576.3	343222.5	9.2
150	0.25	160	12	5720.3	429022.5	15.3
120	0.3	150	10	5562	333720	13.9

Table -4: Face Milling Calculation

Highlighted specification shows maximum cutting force at which machine reaches its capacity of motor 18.56 KW.This can be validated through PT diagram of BT-50 spindle.

4.2 Drilling Calculation by Software

Drill Diameter (mm)	Cutting Speed (m/min)	Hole Depth (mm)	Feed (mm)	Thrust force (N)	Power(kW)
50	100	50	0.15	5406	7.89
100	**100**	**50**	**0.15**	**10812**	**15.79**
100	**115**	**50**	**0.15**	**10812**	**18.16**
50	115	50	0.15	5406	9.08
80	115	50	0.15	8650	14.52

Table -5: Drilling Calculation

Highlighted results shows that at Drill diameter of 100 with cutting speed 115 m/min will product 10812 N force and it reached the limit of motor that is 18.5 kW.

5 PRESTRESSED ANALYSIS

Under structural loading what will be the response of the system considering modal analysis is called as pre-stressed analysis. Here two type of forces acting on column body one is tangential force while performing face milling operation while other is thrust force which is due to drilling operation as discussed above.

Face milling is operation which generates maximum amount of tangential forces on a body hence it will be act in tangential direction of column here we will consider the cutting force of 6864.4 N. Cutter diameter is 150 mm & feed is 0.3 m/min.

Drilling is operation which generates maximum amount of thrust force on a body hence it will be act in front of a column face and amount of force will be 10812N.Cutter diameter is 100 mm & feed is 0.3 m/min.

5.1 Boundary condition for Pre-stressed analysis of face milling

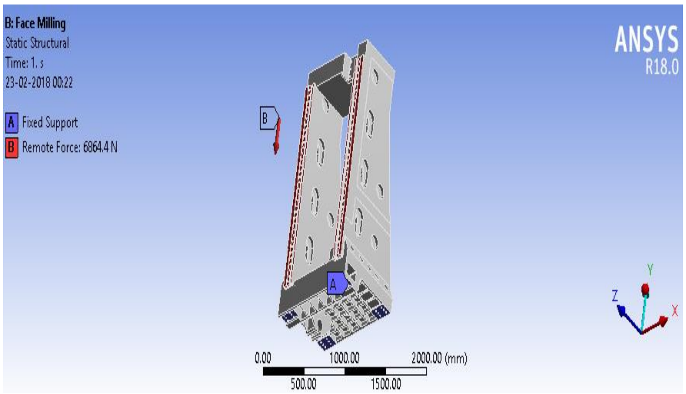

Fig -6: Boundary condition for pre-stress

Here one end of column is having fixed support and tangential force of 6864.4N is acting in +Y direction of front face of the column. Remote force is being used because cutting force of milling is acting on column from a distance of 812 mm which is remotely located and from this point cutting load is being applied in this structure.

5.1 Boundary condition for Pre-stressed analysis of Drilling

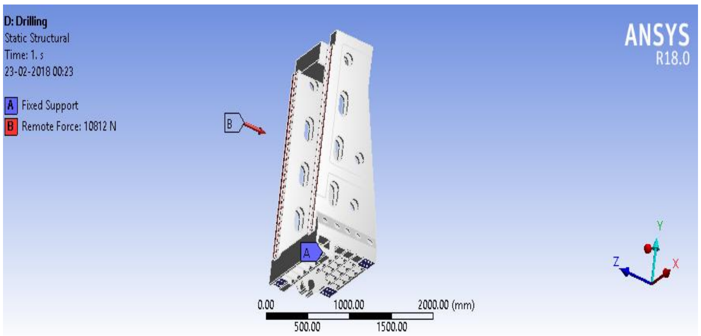

Fig -7: Boundary condition for pre-stress

Figure shows how remote boundary condition will act on the component. Here point is located nearby 812 mm from front face of the column and which will be act as remote point and transfers whole force form this remote point to column.

5.3 Pre-stressed result

Stress	**Face Milling**	2.32 MPA
Deformation		0.030968 mm
Stress	**Drilling**	4.35 MPA
Deformation		0.03063 mm

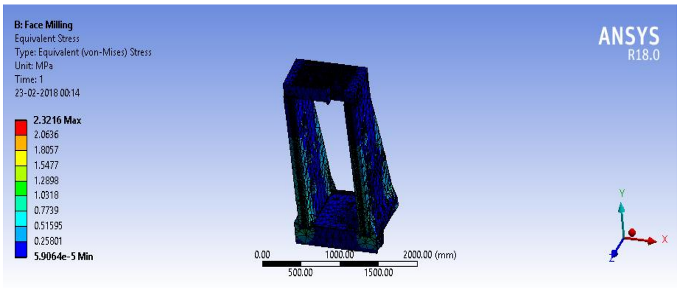

Fig -8: Stress in Face milling

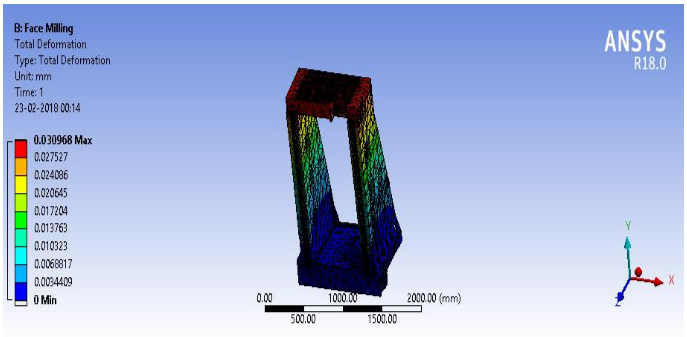

Fig -9: Deformation in Face milling

5.4 Natural Mode shapes & Deformation of face milling

Mode	Frequency [Hz]
1	30.804
2	88.833
3	113.46
4	119.65
5	144.52
6	234.53

Table -5: Pre-stress frequency of face milling

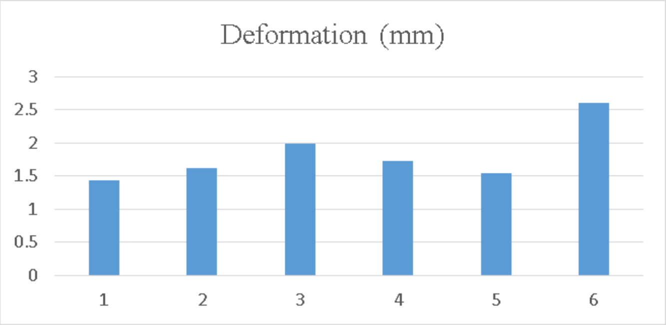

Chart -4 Deformation in Face milling in all mode shapes

5.5 Natural Mode shapes & Deformation of Drilling

Mode	Frequency [Hz]
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Table -6: Pre-stress frequency of face milling

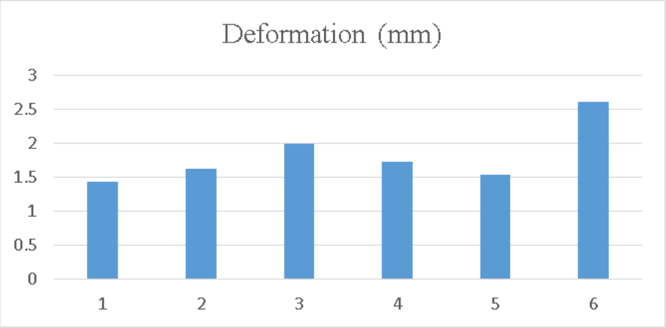

Chart -5 Deformation in Drilling in all mode shapes

6. CONCLUSIONS

Pre-stressed result shows there will be no any frequency which is near by 100 Hz. Hence structure is safe against tangential & thrust force.Stiffness and natural frequency consideration is more important while designing structural part which is to be worked under heavy payload condition. Considering pre-stress vibration gives more idea about structure that how it will behave in case of applying certain steady state loads and according to that safe structure design is being carried out.

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